Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Geologic Sequestration

Volumetric Equations for CO_2 Storage in Coalbeds, Oil and Gas Reservoirs, and Saline Formations

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Volumetric Equations for CO_2 Storage in Coalbeds, Oil and Gas Reservoirs, and Saline Formations

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Outline

- General Volumetric Equation
- Displacement Efficiency
- Saline Water Bearing Formation
- Oil Reservoir
- Gas Reservoir
- Coalbed

General Volumetric Equation

$$m = c\ A\ h\ \phi\ S/B$$

m	mass of the stored fluid
A	areal extend of the formation
h	vertical “net” thickness of the formation
ϕ	porosity, fraction of the bulk volume (Ah)
S	saturation, fraction of the pore volume (Ahϕ)
B	conversion from subsurface to surface volume
c	conversion from volume to mass

Units

m	mass, metric tonne
A	area, acres
h	thickness, feet
ϕ	porosity, fraction
S	saturation, fraction
R	scf/bbl (standard ft^3)
ρ	std gas density, lbm/ft^3
ρ_c	coal density, gm/cc

Displacement Efficiency

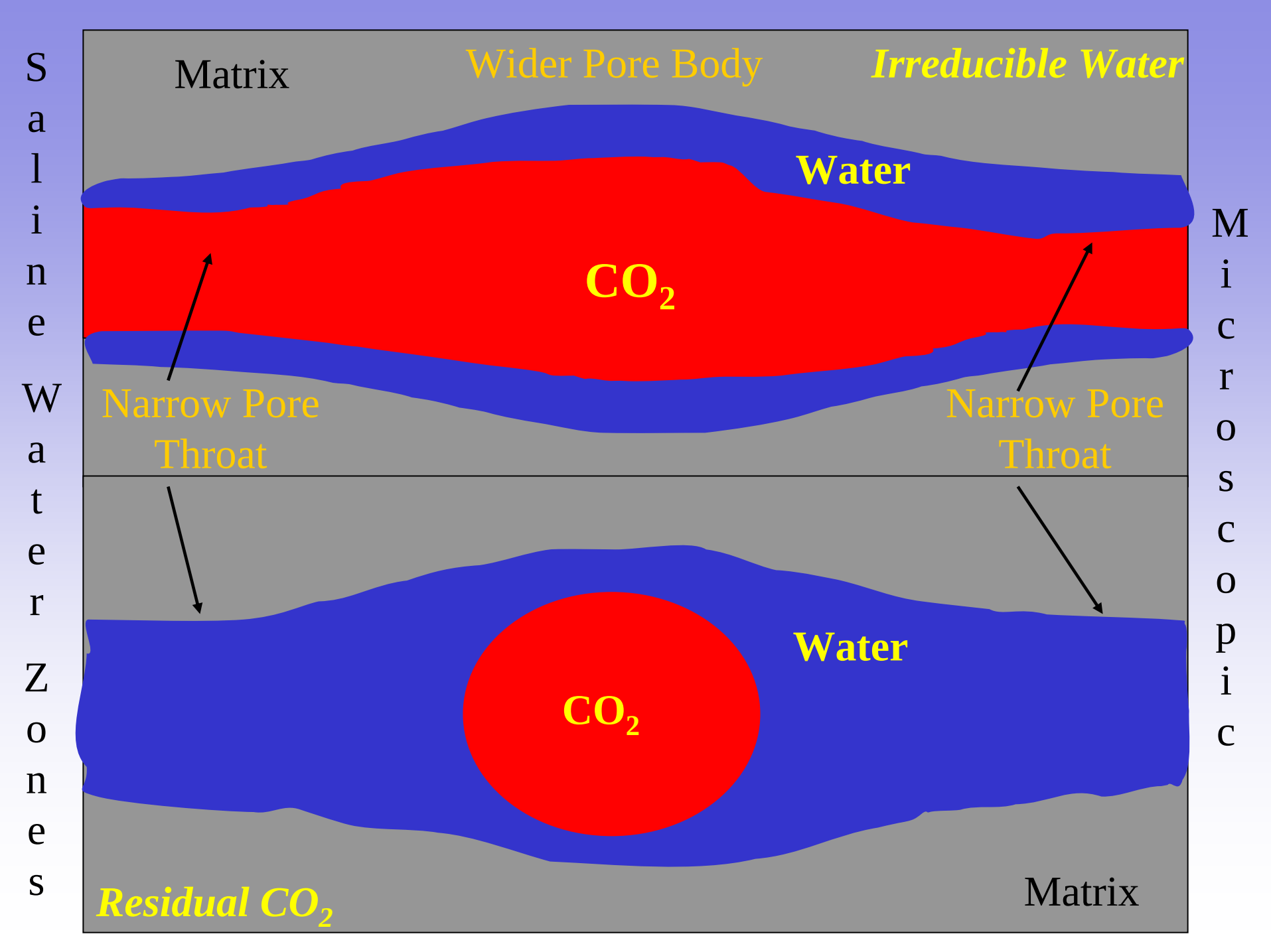
- Storage Factor (E) is the product of *microscopic* (E_D) and *macroscopic* (E_V) displacement efficiency

$$E = E_D E_V$$

Displacement Efficiency, contd.

- Microscopic Displacement
  - Initial fluid (water, oil or gas) saturation
  - Residual fluid (water, oil or gas) saturation

- E_D
- Process dependent
- Differs for
  - In situ fluid(s)
  - Geologic formations

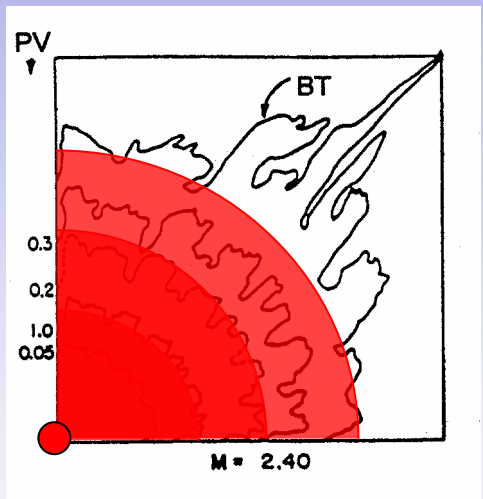

Saline Water Zones
Matrix
Wider Pore Body
Irreducible Water
Water
CO_2
Narrow Pore Throat
Narrow Pore Throat
Water
CO_2
Residual CO_2
Matrix
Microscopic

Displacement Efficiency, contd.

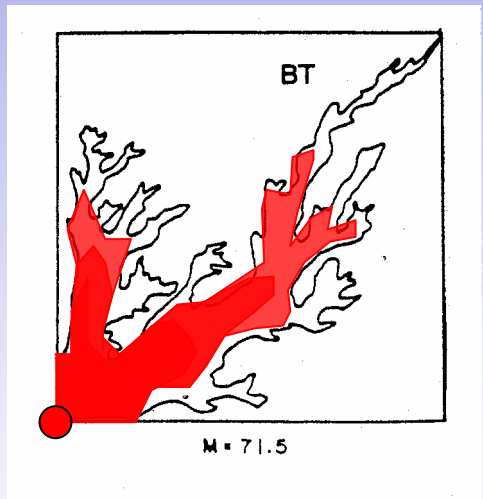
- Macroscopic Displacement
  - Areal sweep efficiency (E_A)
  - Vertical sweep efficiency (E_I)
- $E_V = E_A E_I$

- E_V
- Process dependent
- Geologic heterogeneity
- Injector/producer
  - Pattern
  - Spacing

Areal Sweep Efficiency (Macroscopic)



CO_2 Injector



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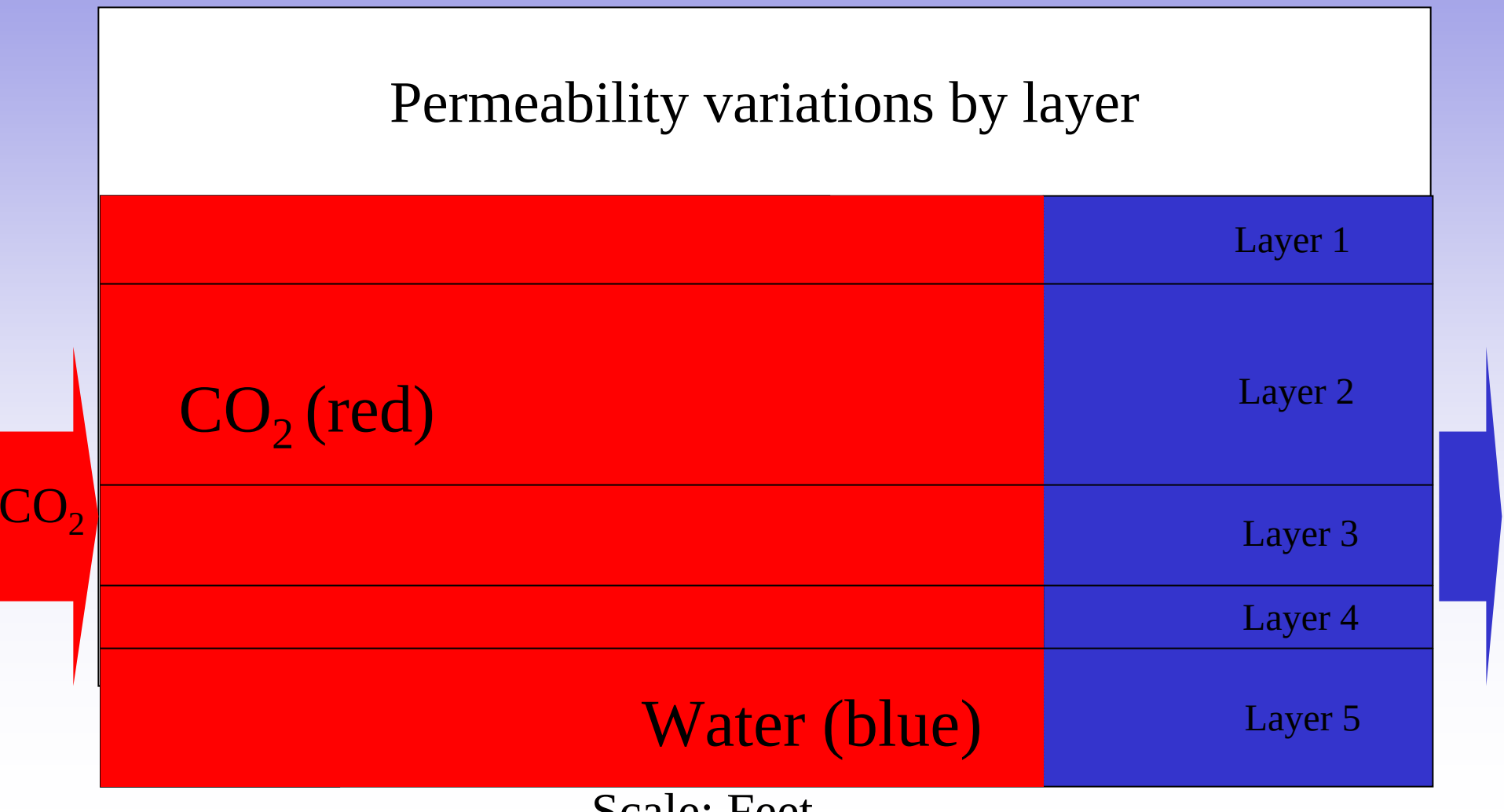
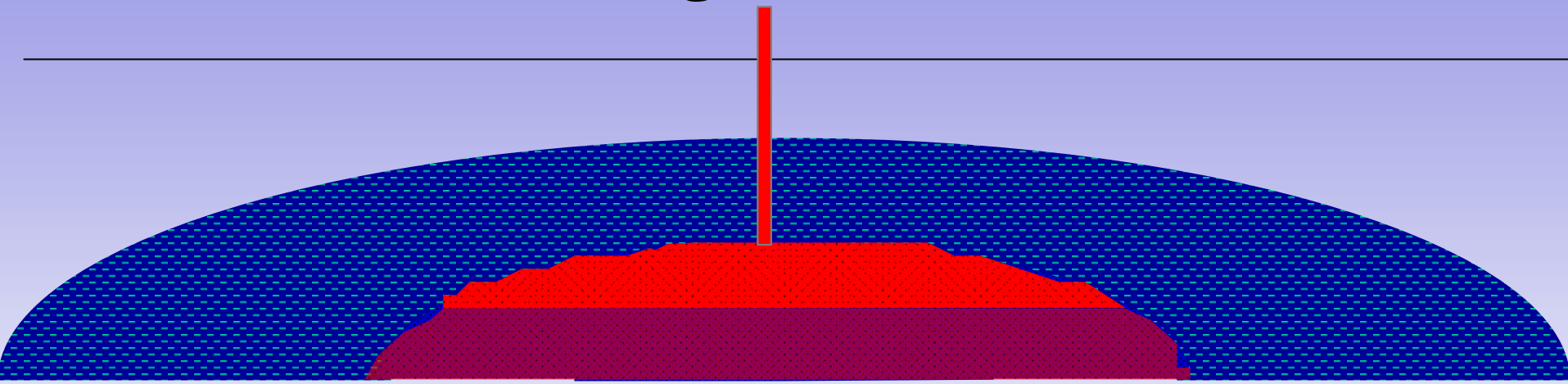
(Plan View)

Vertical Sweep Efficiency (Macroscopic).

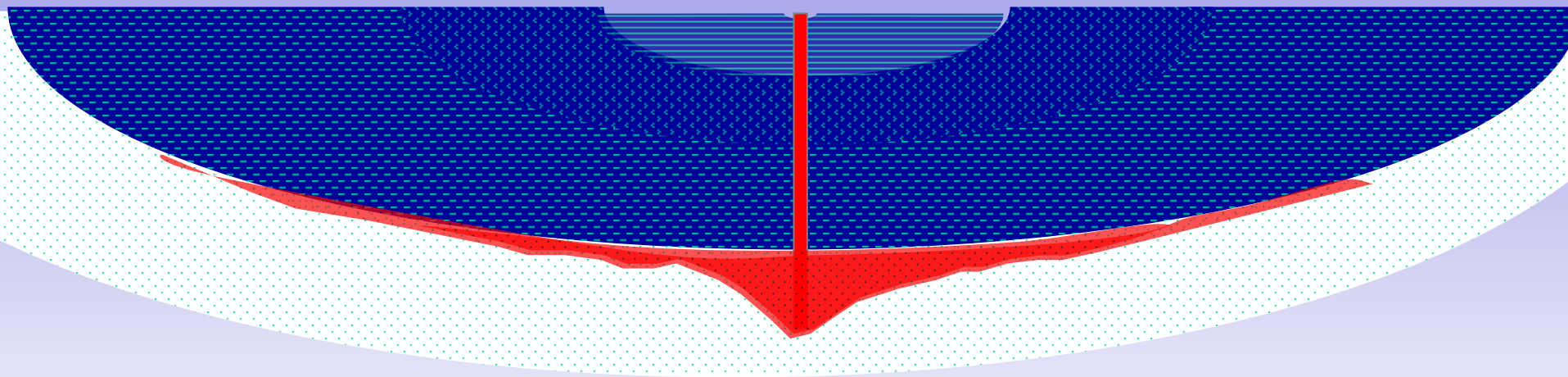


Saline Formation Storage Mechanisms: Geologic Structure



- CO_2 less dense than saline water in saline formation
- CO_2 “pool” forms at the top of subsurface geologic structure then dissolves in water with time.

Saline Formation Storage Mechanisms: No Geologic Structure



- No CO_2 “pool” forms at the top of subsurface geologic structure
- CO_2 continues to migrate until a geologic trap is reached, CO_2 is capillarily trapped or dissolves in water.

Saline: Storage Capacity Equations

$$19.76\,Ah\phi\rho_{CO2}(1-S_{wirr})E_{Vm}$$

$$3.519\,Ah\phi\rho_{CO2std}R_{sCO2/w}S_{wirr}E_{Vm}$$

$$19.76\,Ah\phi\rho_{CO2}S_{CO2irr}E_{Virr}$$

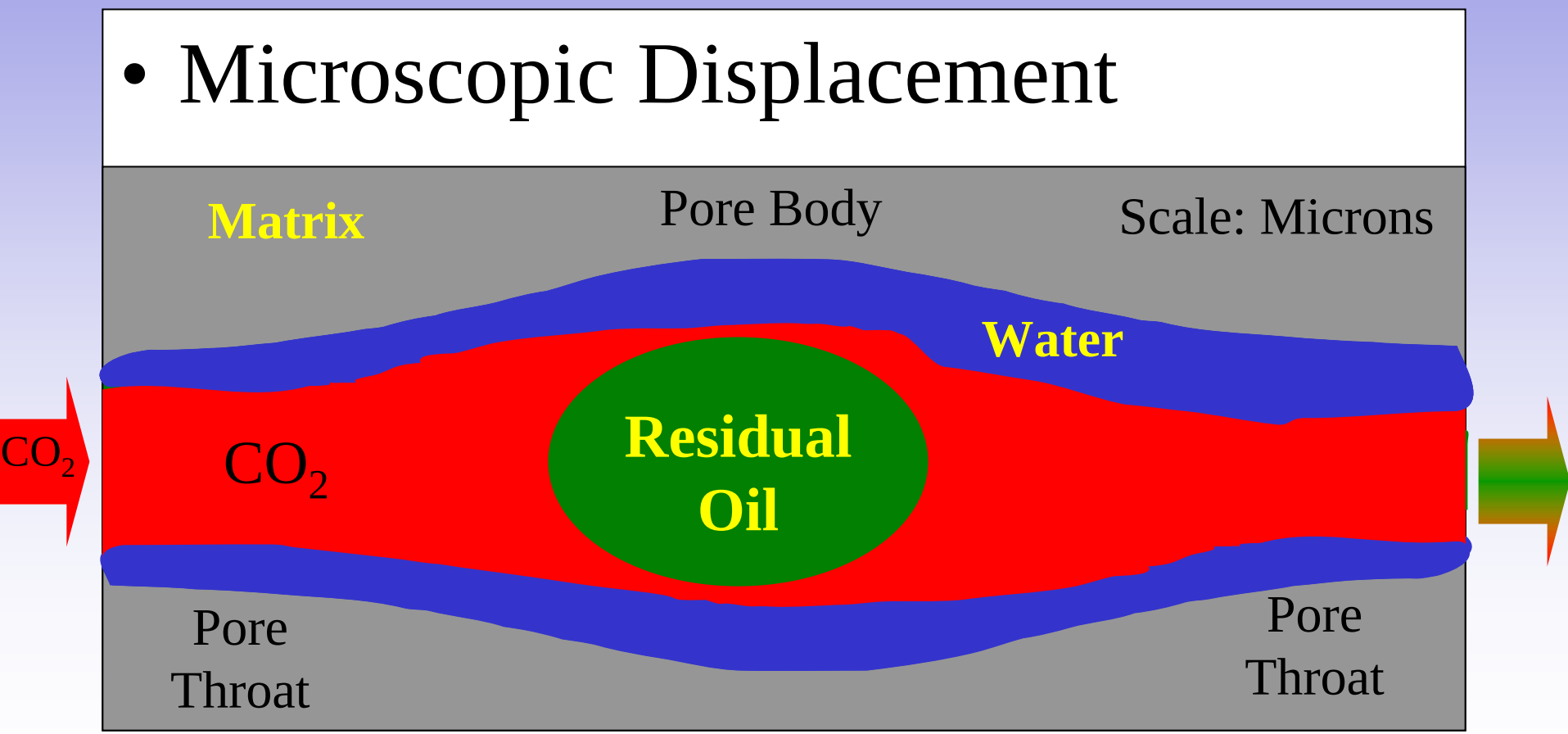
$$3.519\,Ah\phi\rho_{CO2std}R_{sCO2/w}(1-S_{CO2irr})E_{Virr}$$

$$3.519\,Ah\phi\rho_{CO2std}R_{sCO2/w}(1-E_{Vm}-E_{Virr})$$

- Mobile, Free Phase (*Structurally Trapped*)
- CO_2 Saturated Brine, Swept to S_{wirr}
- Immobile, Free Phase (*Capillary Bound*)
- CO_2 Saturated Brine, Swept to $1\text{-}S_{co2irr}$
- CO_2 Saturated Brine, Unswept

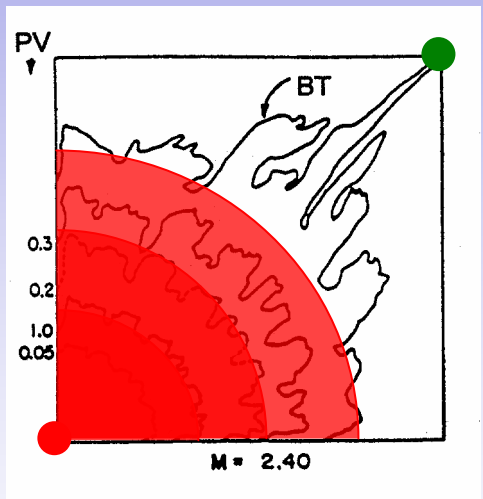
Oil Reservoirs

- Microscopic Displacement



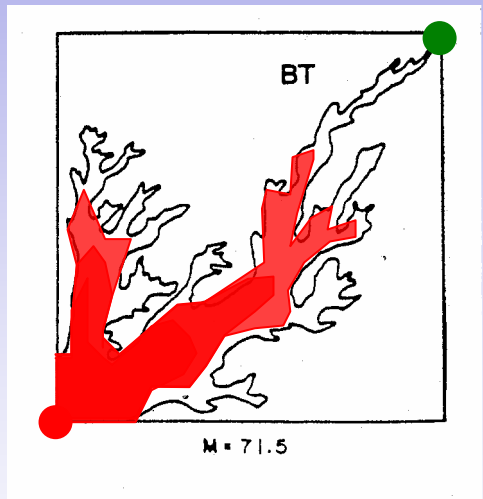
Oil Reservoirs: Heterogeneity-Anisotropy and/or Pattern Efficiency

Oil Producer



CO_2 Injector

Oil Producer



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(Plan View)

Oil: Storage Capacity Equations

$$19.76\,\rho_{CO2}hA\phi S_g$$

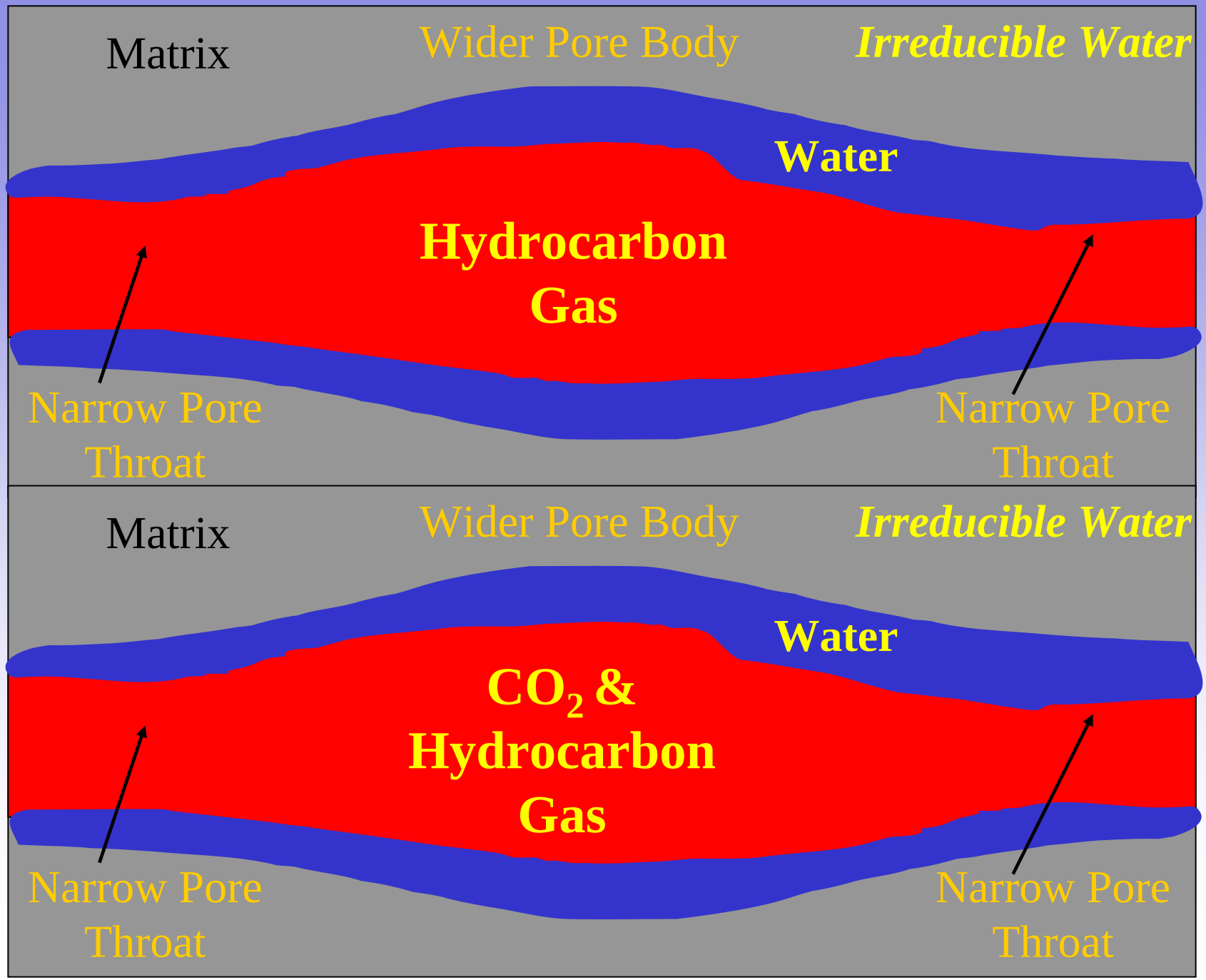
$$19.76\,\rho_{CO2}hA\phi S_o E_V$$

$$3.519\,\rho_{CO2std}R_{sCO2/oil}hA\phi S_{or}E_V$$

$$3.519\,\rho_{CO2std}R_{sCO2/w}hA\phi S_w E_V$$

- Mobile, Free Phase CO_2 (replaces hydrocarbon gas)
- Mobile, Free Phase CO_2 (replaces EOR)
- CO_2 Saturated Residual Oil
- CO_2 Saturated Water

Gas Reservoirs



Gas: Storage Capacity Equations

$$19.76\,\rho_{CO2}hA\phi S_g$$

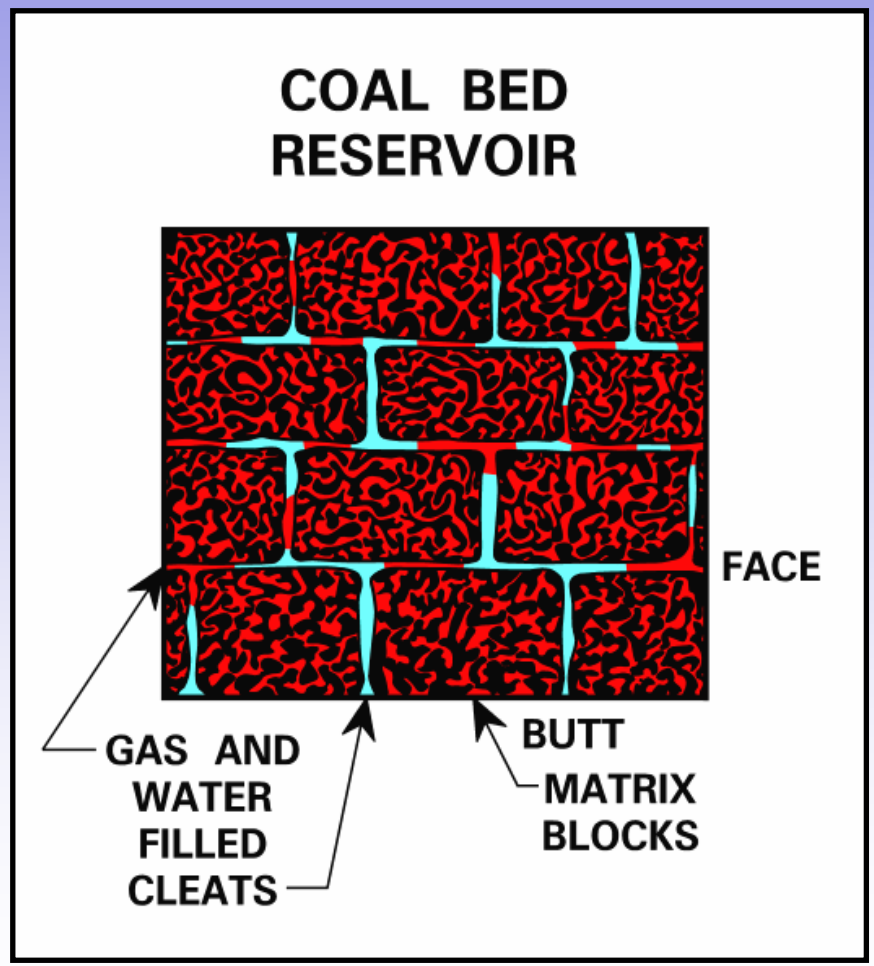
$$3.519\,\rho_{CO2std}R_{sCO2/c}hA\phi S_{cr}E_V$$

$$3.519\,\rho_{CO2std}R_{sCO2/w}hA\phi S_wE_V$$

- Free Phase CO_2 (mixed with hydrocarbon gas)
- CO_2 Saturated Residual Condensate (liquid)
- CO_2 Saturated Water

Coalbeds

- Cleats
  - Permeable conduit of gas to and from the coal
- Coal matrix
  - Primary Methane gas source (adsorbed) and CO_2 storage potential
- Water in cleats

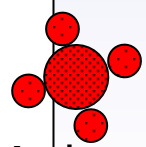


Provided by T. Moore

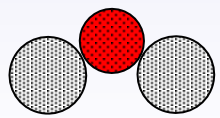
Coalbeds: ECBM

- Microscopic Surface Phenomena of attractive forces between molecules
- Adsorption/desorption of Methane
- Preferential adsorption of CO_2 over Methane

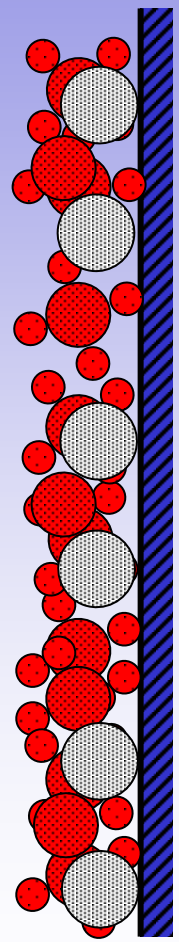
CO_2 Injection Lower Pressure via water production from Cleats



Methane



CO_2



COAL INTERNAL SURFACE

Coal: Storage Capacity Equations

$$0.6168\rho_{CO2std}C_{CO2i}\rho_c Ah(1-\phi)(1-f_a-f_m)E_v$$

$$19.76\rho_{CO2}hA\phi(1-S_w)E_v$$

$$3.519\rho_{CO2std}R_{sCO2/w}hA\phi S_w E_V$$

- CO_2 Adsorbed to Coal
- Mobile, Free Phase CO_2 (cleats)
- CO_2 Saturated Water (cleats)

Summary

- Presence of minerals with CO_2 adsorptive capability in saline water bearing formations and oil and gas reservoirs can be added similarly to the coalbed equation.
- Mineralization changes the type of storage but likely not the capacity during the active injection period of a sequestration site

Conclusions

- Storage mechanisms have been identified to model storage capacity in saline water bearing formations, oil and gas reservoirs, and coal beds.
- Volumetric equations have been developed to assess the CO_2 storage (mass) using a storage factor (efficiency)

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